Chapter 2
Description of Radioactive Waste Sites

2-1. Introduction

In the following paragraphs the activities or types of facilities that result in the production of radioactive materials that may be encountered in site remediations are summarized, along with the types of materials produced and their characteristics.

2-2. Hazards from Radioactivity

a. Radiation hazard. Radiation is hazardous because it ionizes atoms and molecules during its passage through biological cells (particularly alpha particles). This means that electrical charges and molecular structures are changed. Resultant changes in the chemicals in which the electrical balance and molecules have been disrupted cause the cell functions to be disrupted. Large doses of ionizing radiation may cause sufficient cell damage to interfere with critical bodily functions or cause permanent changes in genetically inheritable cell structures. LLRW or MW site remediation can expose the unprotected worker to radioactive hazards in the form of sources external to the body or by inadvertent intake of radionuclides (e. g., alpha sources).

b. Nature of radiation types. Many types of radiation comprise radioactivity. The types, as well as the intensities, of radiation determine safety procedures, shielding, and remediation methods. Shielding and other protection methods are technical application subjects which are highly dependent on the physical and chemical nature of the LLRW and MW and on the site conditions. A health physicist knowledgeable in details of the site and materials present will establish the necessary types and amounts of shielding and work practices protecting against radiation hazards.

(1) Alpha radiation is subatomic particles that carry a double positive electric charge and that are identical to the nucleus of a helium atom, consisting of two protons and two neutrons. Alpha radiation has a shorter range and lower penetrating power than other forms of radiation. Alpha radiation can be stopped by the equivalent of a sheet of paper or the normal layer of dead skin cells. Alpha radiation is most hazardous when its source is inside the body after being inhaled or ingested because of its high ionization capability (high mass and electrical charge).

(2) Beta radiation is subatomic particles that can carry either a positive (positron) or negative (beta particle) electrical charge and are comparable in mass to an electron. Low energy beta particles can be stopped by the equivalent of aluminum foil or a few centimeters of air. More energetic beta particles (e.g., from Sr-90) penetrate deeper. Beta radiation is best shielded with hydrogen-bearing compounds to reduce beta-conversion-generated gamma radiation. Beta radiators are hazardous when they are on the skin, in the eyes, or inside the body.

(3) Gamma radiation and X-rays are electromagnetic waves like light or radio waves. This radiation has very high energy and very short wavelengths. Gamma and X radiation penetrates all material to some degree depending on the radiation intensity, the density of the material, and the thickness of the material. Gamma and X radiation is attenuated most by atomically dense materials such as lead. Dense materials (e. g., lead) used as attenuators need not be as thick to be effective as do less dense materials such as concrete. Because gamma and X radiation penetrates matter so effectively, it is a hazard to the entire body regardless of whether its source is internal or external.

(4) Neutron radiation is the emission of subatomic particles like alpha and beta radiation, though it possesses no electrical charge and is one quarter the mass of an alpha and much more massive than a beta particle. Penetrating power (and the power to do biological harm) is dependent on the speed of the neutron particle. Slow neutrons have low energy; faster neutrons have higher energy and can penetrate farther through shielding. Low to medium energy neutron radiation can be stopped completely by materials such as ordinary concrete. Materials consisting of hydrogen compounds (e. g., water, paraffin, etc.) and others (e. g., boron) are particularly effective in shielding from neutron radiation. Neutron radiation can also be absorbed by otherwise stable nuclei, thus making them radioisotopes.

c. Mitigation of radiation hazards. Individuals may reduce the hazards of radiation in three ways. Time of exposure to the radiation should be kept to a minimum because the effects of ionizing radiation accumulate during exposure. Distance from the radioactive material should be kept as large as reasonably possible because radiation is a quantifiable phenomenon and as a given quantity radiates from its source through a volume, its intensity is diminished by spreading. Shielding materials such as lead, concrete, or water will reduce radiation exposures.

d. External radiation.

(1) External radiation may originate from a radioactive material sealed or otherwise contained inside a closed item. External radiation occurs when the body is exposed to an ionizing radiation source externally and the radiation penetrates into tissues. The actual radioactive material is not exposed for possible direct ingestion.

(2) Time minimization, distance maximization, and shielding protect the worker from external radiation.

(3) Film badges and dosimeters record the amount of accumulated radiation exposure the individual has received. Instrumentation can measure the amount and intensity of external radiation present at a location.

e. Surface radioactive contamination.

(1) Surface radiation contamination occurs when radioactive material is deposited on or induced into surfaces of objects, personnel, or structures. Surface contamintion generally occurs when radioactive materials are mechanically deposited, deposited after being water- or airborne, or when neutron radiation activates stable elements into radioisotopes. Surface contamination continues to be an external hazard until the contaminant is taken into the mouth or lungs, or is absorbed through the skin or open wounds; then, it becomes an internal radiation hazard to the individual ingesting the material. Neutron-activated surface contamination is generally fixed onto the surface and less likely to be ingested or inhaled. Deposited surface contamination is usually spreadable or removable and presents the hazard of being ingested or inhaled.

(2) Surface contamination may originate by leakage from a sealed container holding radioactive material, by spilling radioactive material from a container, or by the presence of radioactive material that was never contained. Fixed contamination is radioactive material that tightly adheres to a surface or comprises the surface itself. The hazard from true fixed surface contamination is entirely from external radiation. Removable surface contamination is readily accessible and can be transferred to the skin, to clothing, to tools, etc. Individuals and equipment can move such surface contaminants into formerly uncontaminated zones. Fixed surface contamination can be changed into removable, transportable contamination by disrupting its structure, breaking it up, burning it, digging it up, etc.

(3) Protective clothing can protect the individual from transportable radioactive contaminants. Hand and facial coverings are very important in preventing surface radiation hazards from being accidentally ingested (and becoming the more serious internal hazard) or carried out of the controlled work area. Clothing that has surface contaminants on it is removed before the worker leaves the contaminated area. Hand and face coverings, tools, or work items can be placed in sealed containers or bags if their surfaces may have been contaminated. walls, floors, large equipment, and workers' bodies can be washed thoroughly to remove surface contaminants.

f. Airborne radioactive contamination. Airborne contamination arises as particulate in the air which are radioactive. Certain gaseous radioisotopes such as iodine and radon could be present at M W sites, but the most frequent occurrences will be particulate-borne. Filtered or self-contained breathing apparatus may be necessary in the presence of airborne contamination to prevent it from becoming an internal hazard. Ventilation of confined areas is a necessity to protect against airborne contamination because the chances of concentration of the contaminant are greater. Typical dust control measures will be effective in reducing the hazard of airborne radioactive particulate.

g. Waterborne radioactive contamination. Radioactive particles may be suspended in water; radioisotopes may be dissolved in water. To workers at an HTRW remediation site, waterborne contamination will be a relatively minor external hazard. Waterborne radioactive materials, however, are the most pervasive contamination pathways to the general populace and the environment. Much of HTRW site remedial investigative and cleanup work intended to prevent offsite migration will deal with waterborne radioactive contamination.

2-3. Low-Level Radioactive Waste (LLRW)

a. Low-level radioactive waste definition. LLRW is defined as all radioactive waste except high-level waste and uranium or thorium mill tailings. This definition was erected for purposes of determining methods of disposal of LLRW and high-level radioactive wastes. Most radioactive waste that USACE may deal with is LLRW. LLRW should not be construed to present low hazards. The hazards of radioactive wastes are determined by the type and quantity of radiation emitted.

b. Low-level radioactive waste classification. For disposal of LLRW at near-surface disposal sites, a classification system, based on the longevity and the radiation emitted, has been developed to segregate wastes by hazard. Two considerations are taken into account when classifying LLRW: the concentration of long-lived and the shorter-lived radionuclides. Table 2-1 lists the concentrations of radionuclides used by the NRC to define LLRW. Certain requirements must be met for all classes of LLRW, and are intended to facilitate handling and provide protection to site personnel, the nearby public, and potential intruders into the disposal facility. LLRW is then classified as to the degree of rigor of the required disposal method.

c. Waste form characteristics. The acceptable physical characteristics of LLRW and the containers it is disposed in are determined by the license conditions of the disposal site. For near-surface disposal at compact state disposal facilities, the following characteristics are usually required. For LLRW to be disposed of at Envirocare or other facilities, the acceptable characteristics are listed in the site license. Exemptions may be applied for and are granted if there is no increase in the hazards or risk to the public and environment.

(1) Waste may not be packaged in cardboard or fiberboard boxes.

(2) Liquid LLRW must be solidified or packaged in sufficient absorbent material. Solid LLRW containing liquid shall contain as little free noncorrosive liquid as possible, not to exceed 1 percent by volume.

(3) LLRW must not be capable of detonation, explosion, or any other violent decomposition under ordinary disposal unit conditions.

(4) LLRW shall not contain or generate quantities of toxic fumes or gases during handling, transport, or disposal.

(5) LLRW must not be pyrophoric; waste containing pyrophoric materials shall be treated to be nonflammable.

(6) Gaseous LLRW must be packaged at less than 1.5 atmospheres pressure at 20 “C and each such container will not contain more than 100 Ci total.

(7) LLRW containing hazardous, biologic or pathogenic or infectious material will be treated to reduce the potential hazard from nonradiological materials.

(8) LLRW will possess structural stability to avoid degrading the containment and the site. It will generally maintain its physical dimensions and form under the expected disposal conditions. Conditions to consider in assessing structural stability include weight of overburden, presence of moisture, microbial activity, radiation effects, and chemical changes. The waste form itself may provide structural stability before or after processing; or the waste may be placed in structurally stable containers or structures for disposal. Generally, only those stabilization media that have been evaluated according to the stability guidance requirements of the NRC’s Low-Level Licensing Branch, Technical Position on Waste Form, are considered acceptable media. Liquid LLRW must be converted to a form containing as little free-standing and noncorrosive liquid as reasonably achievable. The volumetric content of the LLRW part of liquid or solid waste will not exceed 1 percent of a single container or 0.5 percent of the volume of waste processed to a stable form. Void spaces within the waste and between the waste and its package will be reduced as much as reasonably possible.

d. Class A LLRW. Class A LLRW is waste that does not contain sufficient amounts of radionuclides to be of concern with respect to migration, long-term active site maintenance, and potential exposure to intruders. Class A LLRW tends to be stable. Class A LLRW is usually segregated from other waste classes at the disposal site. Class A LLRW must meet the minimum handling characteristics required and described above. Class A LLRW has concentrations less than Column 1, and less than Column 4 of Table 2-1.

e. Class B LLRW. Class B LLRW must meet more rigorous standards for stability than Class A. Class B LLW is more highly radioactive than Class A. Class B LLRW has concentrations greater than Column 1 and less than Column 2 of Table 2-1.

f. Class C LLRW. Class C LLRW must meet the most rigorous standards on waste form stability and additional measures at the disposal facility to protect against inadvertent intrusion. Class C LLRW has concentrations greater than Column 2 and less than Column 3, and less than Column 5 of Table 2-1.

g. Greater than Class C LLRW. Waste classified as greater than Class C is not suitable for near-surface disposal. Greater than Class C LLRW has concentrations greater than Column 5 of Table 2-1.

h. Radionuclide concentrations. Concentrations may be measured directly or calculated if there is reasonable assurance of correlation to direct measurements. Indirect methods of concentration determination include inference of one nuclide concentration from that of another which

Table 2-1
Radioactive Constituents of LLRW

Concentration Nuclide	Column 1 Ci/m^3	Column 2 Ci/m^3	Column 3 Ci/m^3	Column 4 Ci/m^3	Column 5 Ci/m^3
C-14				0.8	8
C-14 activated metal				8	80
Ni-59 activated metal				22	220
Nb-94 activated metal				0.02	0.2
Tc-99				0.3	3
I-129				0.008	008
TRU with half-life > 5 years				10 nCi/gm	100 nCi/gm
Pu-241				350 nCi/gm	3500 nCi/gm
Cm-242				2,000 nCi/gm	20,000 nCi/gm
All half-lives < 5 years	700				
H-3	40				
Co-60	700				
Ni-63	3.5	70	700		
Ni-63 activated metal	35	700	7000		
Sr-90	0.04	150	7000		
Cs-137	1	44	4600		

is directly measured, and material inventory records. Concentrations may be averaged by weight or by volume. Classification of mixtures of radionuclides is accomplished by comparing the sum of the fractional proportion of each represented radionuclide to a value of 1.0.

2-4. Mixed Waste (MW)

a. Mixed waste definition. A mixed waste may be a listed and/or characteristic waste that is mixed with an NRC-regulated radioactive material. The radioactive components of mixed waste regulated by the NRC or the agreement state are source, by-product, or special nuclear material, and the hazardous component of mixed waste is regulated by the EPA or the RCRA authorized state. A hazardous waste is defined in 40 CFR 261 as a solid waste which exhibits a hazardous characteristic, is "listed" in the regulations, or is a mixture of hazardous and solid wastes.

b. Enhancements to the basic definition. Radioactive materials that are not source, by-product, or special nuclear materials are not regulated by the NRC, but may be regulated by agreement states, depending on state laws. Hazardous wastes that are not RCRA listed or characteristic hazardous wastes may be regulated by the state as a hazardous waste under state hazardous waste management laws. The state does not need to be RCRA-authorized to establish this authority.

c. Mixed, combined, and co-mingled waste. When non-NRC regulated radioactive materials are mixed with RCRA hazardous wastes, or with state-listed hazardous wastes, or when NRC-regulated radioactive materials are mixed with state-listed hazardous wastes, the waste is considered combined waste, which is sometimes called co-mingled waste. The distinction between mixed and combined or co-mingled waste is important due to disposal options. There are a number of disposal options for combined or co-mingled waste, but only a few options for mixed waste.

2-5. Sources and Characteristics of Radioactive Materials, LLRW, and MW

a. Nuclear weapons facilities.

(1) Facility operation description. The nuclear weapons facilities considered here are those where inspection, storage, and maintenance of nuclear weapons are conducted. TRU materials and wastes are present but are not considered herein. Both LLRW and MW are present as by-products of the processes and operations in the facilities. The weapons are disassembled, inspected, repaired, reassembled, and stored until shipped from the facility.

(2) Types of radiation expected. Examples of radionuclides present in nuclear weapons are uranium-233

and -235, plutonium-239 and -241, americium-241, and hydrogen-3. Depleted uranium is also used in testing and training for weapons maintenance. These radionuclides emit alpha, beta, gamma, and X-radiation.

(3) Types of sources present. The radioactive material can be considered a sealed source when a weapon is assembled. During inspection and maintenance, the radioactive material is an unsealed source.

(4) Radioactive contamination potential. There is no potential for radioactive contamination when a weapon is assembled unless it is subjected to severe physical damage or is damaged by fire. When a weapon is disassembled, there is a slight potential for contamination. This potential increases if the radioactive material is damaged in any way during inspection/maintenance activities.

(5) Radioactive waste generated. Very small volumes of slightly contaminated solid waste can be generated during inspection/maintenance activities. No significant amount of liquid radioactive waste is generated.

(6) Potentially contaminated areas. Areas of potential contamination include disassembly, inspection, maintenance, and reassembly areas; radioactive waste-handling and packaging areas; and decontamination facilities. Sinks, drains, trash receptacles, and formerly used radioactive waste disposal cells are particularly probable contaminated areas.

b. Research laboratories,

(1) Facility operation description. Depending on its mission, a research laboratory may be involved in a wide variety of activities including the analysis of materials activated by neutron radiation, the effects of radiation exposure on animals, and the use of radioactive tracers in chemistry experiments. Various radionuclides may be used in a typical laboratory environment or may be used in closed, shielded cells to protect personnel from radioactive hazards. A reactor or accelerator may also be used at the facility.

(2) Types of radiation expected. Depending on the facility mission, a number of different radionuclides may be used, and alpha, beta, X, gamma, or neutron radiation can be expected to occur.

(3) Types of sources present. Sealed, partially sealed, and unsealed sources can be expected to be used.

(4) Radioactive contamination potential. There is a high potential for contamination in any area of a laboratory where unsealed sources are used in experiments and studies.

(5) Radioactive waste generated. Moderate to large volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste can also be generated. Research labs characteristically produce larger quantities of MW compared to LLRW.

(6) Potentially contaminated areas. Areas of potential contamination include:

(a) Laboratory areas (bench tops, fume hoods, glassware, centrifuges, scintillation counters, hot cells, and refrigerators used for radioactive material storage).

(b) Animal cage areas.

(c) Solid radioactive waste-handling and packaging areas.

(d) Liquid radioactive waste system (tanks, pumps, valves, piping).

(e) Ventilation system (ducting, filters, filter housings).

c. Medical facilities.

(1) Facility operation description. Medical facilities perform a variety of diagnostic and therapeutic procedures using radioactive materials and radiation-producing machines. For diagnostic procedures, radioactive material may be injected into a patient in liquid form or taken orally. Radiation-producing machines such as X-ray units and computerized tomography scanners may be used. For therapeutic procedures, radioactive material may be injected into a patient in liquid form, taken orally, or implanted in solid form. These implanted sources may remain in the patient or can be removed later. Accelerators and highly radioactive cobalt-60 source capsules are also used for radiation therapy.

(2) Types of radiation expected. Beta, X, or gamma sources could occur.

(3) Types of sources present. Sealed, partially sealed, and unsealed sources can be expected to be used.

(4) Radioactive contamination potential. There is a high potential for contamination where unsealed sources are used for diagnosis or therapy. Most unsealed radionuclides used in medicine have short half-lives and, therefore, may not present major decontamination problems for decommissioning. There is a minimum potential for contamination when sources are implanted if the sources are mishandled. There is a slight potential for contamination from sealed sources such as high-radioactivity cobalt-60 sources which are used in radiation therapy units. Contamination may occur from activation products created by high-energy accelerators (> 10 million electron volts) used in research-oriented medical facilities.

(5) Radioactive waste generated. Small to moderate volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste will be generated.

(6) Potentially contaminated areas. Areas of potential contamination may include the following:

(a) Radiopharmacies which are producing, storing, or dispensing radioactive drugs.

(b) Laboratories where liquid sources are prepared for use.

(c) Operating rooms where sources are implanted.

(d) Patients' rooms and examination rooms where patients who have been administered radioactive materials are located.

(e) Nuclear medicine hot labs.

(f) Solid radioactive waste-handling, packaging, and storage areas.

(g) Liquid radioactive waste system (tanks, pumps, valves, piping).

(h) Areas where liquid radioactive sources are stored prior to preparation for administration.

d. Pool reactors and neutron radiography reactors.

(1) These reactors are atmospheric-pressure, water-cooled assemblies generally used to produce long-term, steady-state fluxes of thermal neutron radiation. Some reactors can also produce a high flux of thermal neutron radiation for a very short period of time. The neutron radiation is made available for use outside the reactor by beam ports which penetrate the reactor structure. Items to be irradiated are placed in front of the beam ports.

(2) Primarily gamma and neutron radiation are expected from the reactor. Beta and gamma radiation are expected from the irradiated test items, reactor structures, or impurities in the cooling water.

(3) The reactor fuel elements can be considered a sealed source because the uranium fuel and fission products are contained in cladding. Impurities in the cooling water which become activated can be considered an unsealed source. Any radioactive material resulting from neutron activation of test items or reactor structures could be classified as sealed or unsealed sources based upon the types of materials being activated. Sealed and partially sealed sources will be used for instrument checks and calibrations.

(4) The potential for contamination in a pool-reactor facility can be characterized as moderate. The radioactive material in the cooling water, which results from neutron activation of impurities, is earned through the cooling system and deposited in pipes, valves, pumps, and other system components. When these components are opened for maintenance or repair, or if leaks occur, contamination is likely. The inventory for the coolant radioactive material will be increased if the fuel cladding leaks or is damaged in some manner, releasing fission products into the cooling water. If neutron activation of test items or the structures surrounding a reactor occurs, the radioactive material will be fixed and will act as a source only when the material is dislodged.

(5) Moderate volumes of solid and liquid radioactive wastes will be produced at this type of facility.

(6) Areas and other sources of potential contamination include:

(a) Area housing the reactor.

(b) Areas housing the reactor auxiliary system.

(c) Test items.

(d) Beam ports and equipment used to handle activated test items.

(e) Maintenance areas.

(f) Solid radioactive waste-handling and packaging areas.

(g) Liquid radioactive waste system (tanks, pumps, valves, piping).

(h) Ventilation system (ducting, filters, filter housings).

(i) Decontamination areas.

e. Power reactors.

(1) Facility operation description. The majority of the power reactors in the United States are pressurized water reactors (PWR'S) or boiling water reactors (BWR'S). Other types of reactors include gas-cooled, liquid metal, and heavy water. The reactor fuel produces large amounts of heat as a result of the fission process. This heat is used to generate steam directly in a BWR or is carried by the coolant in the primary system to the steam generator in a PWR or other indirect-cycle reactors. The heat is transferred through the walls of the tubes in the steam generator to the water in the secondary side of the steam generator. The temperature is sufficiently high to change the secondary water into steam. In most plants, the steam travels to a turbine which drives an electric generator to produce electrical power.

(2) Types of radiation expected. Primarily, gamma and neutron radiation are expected from the reactor. Beta and gamma radiation are expected from the irradiated reactor structures or impurities in the coolant. Alpha, beta, and gamma radiation may arise from the spent fuel rods stored at the facility.

(3) Types of sources present. The fuel rods inside the reactor itself can be considered sealed sources, because the uranium fuel and fission products are contained in cladding. However, cladding failure may result in the release of radioactive fission products to the surrounding coolant. Impurities and corrosion products in the reactor coolant which become activated can be considered an unsealed source. Any radioactive material resulting from neutrons activating reactor structures would be classified as a partially sealed source. Sealed and partially sealed sources will be used for instrument checks and calibrations.

(4) Radioactive contamination potential. The potential for contamination in a power reactor facility is greater than that in other facilities due primarily to repair and maintenance activities. The radioactive material in the reactor coolant. which results from neutron activation of corrosion products and fission products from fuel-cladding failures, is carried through the system and deposited in pipes, valves, pumps, the steam generator, and other components. When these components are opened for maintenance or repair, or if leaks occur, contamination is likely. The radioactive material inventory will be greatly increased if a substantial number of fuel-cladding leaks occur or the fuel is damaged in some manner, releasing fission products into the primary coolant. When neutron activation of the structures surrounding a reactor occurs as the system ages, the radioactive material is fixed and acts as a source when the material is dislodged through corrosion and erosion.

(5) Radioactive waste generated. Great volumes of solid and liquid radioactive waste can be produced at this type of facility.

(6) Potentially contaminated areas. Areas of potential contarnination include:

(a) Area housing the reactor.

(b) Areas housing reactor auxiliary systems.

(c) Maintenance areas.

(d) Equipment decontamination areas.

(e) Personnel decontamination areas.

(f) Protective clothing laundry area.

(g) Respiratory protective equipment decontamination area.

(h) Solid radioactive waste-handling and packaging area.

(i) Liquid radioactive waste-system (tanks, pumps, valves, piping).

(j) Ventilation systems (ducting, filters, filter housings).

f. Accelerator facilities.

(1) Facility operation description.

(a) Particle accelerators are radiation-producing machines used for medical, industrial, and research purposes.

(b) Electron linear accelerators (linacs) are used to produce a primary beam of electron radiation (similar to beta radiation though highly directive and of much greater energy) or a secondary beam of X-radiation (similar to gamma radiation) for use in therapy. The patient is positioned relative to the output beam port of an electron lime and the machine is energized for the time required to produce the amount of radiation desired for the therapy.

(c) Electron limes are used in industrial applications to produce a secondary beam of X-radiation which is a penetrating, electromagnetic radiation. The radiation is used for the radiography of such items as welds, castings, and munitions. Electron linacs are used in research applications to determine the effects of irradiation on various materials under study.

(d) Other types of particle accelerators are used for engineering physics research.

(2) Types of radiation expected. Electrons make up the primary beam of electron limes. If the output energy of electron linacs exceeds about 10 million electron volts, neutrons may be produced. Other types of particle accelerators emit alpha particles or other nuclear particles, resulting in secondary radiations and activation of materials. The activated material normally decays by beta- (positive or negative) and gamma-radiation emission.

(3) Types of sources present. Limes incorporate radioisotopes of various species in their sources and in some of their targets. If the output energy of an electron linac exceeds about 10 million electron volts, neutron radiation may be produced. This neutron radiation and output from other types of particle accelerators may activate areas of the device around the output beam port and the structure surrounding the device. If this occurs in solid objects, the radioactive material is considered a sealed source; activated liquids or gases will usually be in unsealed form and more mobile.

(4) Radioactive contamination potential. There are several different types of particle accelerators. Each type and its specific operation must be reviewed to determine the potential contamination.

(5) Radioactive waste generated. No liquid or solid radioactive waste is expected unless the electron linac exceeds 10 million electron volts, in which case small volumes of solid, liquid, or gaseous waste resulting from neutron activation may be produced. Small volumes of radioactive waste may be generated by other types of particle accelerators.

(6) Potentially contaminated areas. If the output energy of electron limes is less than 10 million electron volts, none of the surrounding structure will be contaminated. Energies greater than 10 million electron volts from electron linacs or other particle accelerators will activate components, targets, and surrounding structures, which may result in contamination from loose or disturbed material, during maintenance of the devices, and during decommissioning of the devices.

g. Radiographic facilities.

(1) Radiographic facilities using electromagnetic radiation.

(a) The primary purpose of radiographic facilities is to nondestructively test items for defects. For example, welds are radiographed to reveal any hidden porosity or cracks, castings, or radiographed to reveal any hidden voids, and munitions are radiographed to check for proper assembly. Electromagnetic radiation penetrates a test item and exposes a sheet of film or array of detectors in the same manner that light exposes film or video systems to produce an image. Radiographic films are processed and checked for defects in the item radiographed. The electromagnetic radiation needed for radiography may be produced by a sealed source of radioactive material such as cobalt-60 or iridium-1 92, or by X-ray machines or election linacs. Sealed radioactive sources must be housed in shielded containers when not in use. The containers may be fixed or portable. X-ray machines require no shielding when not in use because radiation is produced only when a machine is electrically energized. Shielding is required when a machine is energized. X-ray machines may be installed in a fixed configuration or may be portable.

(b) Gamma radiation is expected from sealed radioactive sources. Linacs may be used to generate the radiographic beam and their characteristic radiation and waste potential should be expected.

(c) When radioactive material is used, the sources will be sealed.

(d) There is no potential for contamination from an X-ray machine or from a sealed source unless the source is damaged in a manner which breaches the integrity of the material used to encapsulate the radioactive material, or unless the sealed source leaks for any other reason.

(e) None is expected from most radiographic systerns. However, if linacs are used to generate the radiographic beam, the sources and targets are probable waste sources.

(f) There are none, except in the case of linac-generation radiographic systems.

(2) Radiographic facilities using neutron radiography.

(a) Neutron radiography is used to detect moisture and corrosion in bonded honeycombed structures and to test other materials. The secondary radiations created by the neutrons reacting with the material are detected and displayed on monitors that have the capability of digital and imaging enhancement. Most frequently, sources such as radium-226 or americium-241 can be used as sources of alpha radiation impinging on beryllium. The beryllium is activated by alpha radiation to emit neutrons. The radiography occurs in a shielded and interlocked bay, which is accessible only when the source is withdrawn into a shield.

(b) Neutrons from the source are to be expected. Due to neutron activation, alpha, beta, neutron, and gamma radiation may result from irradiated test items and structural materials.

(c) The source is typically sealed hermetically. Source encapsulation failure may occur, causing the direct release of alpha and neutron radiation. Any radioactive material resulting from activation of test items or structural material can be classified as sealed or unsealed based on the types of material being activated.

(d) The potential for contamination is low for properly used and maintained sources. Abandoned or lost source capsules present a serious hazard. It must be noted that the beryllium used to produce the secondary neutron radiation is a very toxic heavy metal. Neutron activation of test items or the structure surrounding the source of neutrons could result in contamination if the material were dislodged and became loose and spreadable.

(e) Very little waste will be generated that is radioactive so long as proper operational, maintenance, and storage practices are followed. Decommissioning of radiographic equipment will generate the largest portion of LLRW of the entire use cycle. The potential for uncontrolled LLRW or MW is greater in the event of equipment abandonment, fire, or other catastrophic event.

(f) Areas of potential low-level contamination are restricted to the radiography bay and test-material-handling areas.

h. Radioluminous-device storage facilities.

(1) Facility operation description. These facilities store new and used radioluminous devices such as clocks, instruments, gunsights, night-vision testers, exit signs, and radioluminescent airfield lighting systems.

(2) Types of radiation expected. Radioluminescent devices use radioactive sources to energize phosphorescent elements or chemicals. The radioactive materials primarily used to generate luminosity are tritium, promethium-147, krypton-85, and radium-226. Tritium and promethium- 147 emit beta radiation only, krypton-85 emits beta and gamma radiation, and radium-226 emits alpha and gamma radiation. Decay products of radium-226, which are radioactive, will also emit beta radiation. Radon-222 is a gaseous decay product which is an alpha radiator and which poses the risk of inhalation to become an internal source.

(3) Types of sources present. Radioluminous devices may consist of instrument faces with the radiation source painted on or may incorporate vials or capsules of radioluminous materials. Because the devices frequently rely on tritium or radium as primary radiation sources, they have great potential to be effectively unsealed. This is because tritium may be a gaseous radioisotope, and because one of the daughters of the decay of radium is radon, which is a gaseous radioisotope. Guaranteed seals, even of encapsulated radioluminous materials, are difficult to achieve and should not be expected.

(4) Radioactive contamination potential. Radioluminous paint is a probable surface and water contaminant when scraped or dissolved off its substrate. The most serious and difficult contamination arising from radioluminous devices is radon emitted from radium-doped paint. Radon is an alpha-radiator and is readily soluble in water or vulnerable to being inhaled. Once internalized, these sources can cause significant biological damage.

(5) Radioactive waste generated. Damaged equipment components which are painted with radioluminous materials will be LLRW. Maintenance of radioluminous systems will generate contaminated cleanup materials. Radioluminous materials characteristically produce gaseous radioactive contaminants. Tritium and radon are readily soluble in water, are easily spread, and can contaminate biological organisms, soil, and groundwater. The great mobility of radiolurninescent-generated waste makes it difficult to clean up. Fortunately, the low energy levels and the small volumes of the original

sources commonly encountered will lessen the environmental impact.

(6) Potentially contaminated areas. There are none, provided the device containing the radioactive material remains intact. Devices with tritium or radium-226 should be treated as suspect to having leakage because of the gaseous radioisotopes involved.

i. Depleted uranium usage and storage facilities.

(1) Facility operation description. Depleted uranium is used to manufacture various types of munitions. These munitions are stored in various facilities and are used in test and practice firings as well as actual warfare. Depleted uranium has been used as armor in some military vehicles and as counterweights in aircraft. Depleted uranium is also used for shielding radiography and teletherapy sources.

(2) Types of radiation expected. Alpha, beta, and gamma radiation can all be expected. Additionally, the radioactive decay of the uranium will produce a sequence of daughter radioisotopes, each of which generates its own characteristic suite of ionizing radiation.

(3) Types of sources present. The depleted uranium in the stored munitions is encased in aluminum or painted, so this source is considered sealed if the case or paint is intact. After the munitions are fired, the sources would be unsealed because the depleted uranium shatters and is dispersed. Depleted uranium used for shields is usually encased in steel and is considered a sealed source.

(4) Radioactive contamination potential. Airborne dust, machine shavings, cutting lubricants, etc., will arise from the fabrication of components from depleted uranium. Waste disposal areas, water drains, and ventilation ducts will be contaminated by the depleted uranium. Once assembled, there is no potential while the munitions are in storage. After the munitions are fired, there will be contamination of target areas and target materials.

(5) Radioactive waste generated. There is little from storage except for radon-222 (inhalable alpha radiation source) produced as a decay daughter. Large fragments of the depleted uranium dispersed after firing and the contaminated targets may be collected and disposed of as waste. Small fragments and uranium oxide dust are not collected and are generally dispersed around the target site. The volumes and dispersal of this contamination are substantial.

(6) Potentially contaminated areas. Firing ranges and targets are areas of contamination.

j. Maintenance shops repairing components containing magnesium-thorium alloys and depleted uranium.

(1) Facility operation description. Machine shops at Air Force Logistics Command Bases repair aircraft parts consisting of depleted uranium and magnesium-thorium alloys by machining, cutting, drilling, welding, and grinding.

(2) Types of radiation expected. Alpha, beta, gamma, and X-ray from thorium-232 and uranium-238, and radionuclides resulting from their decay are expected.

(3) Types of sources present. Depleted uranium as aircraft counterweights and aircraft components manufactured from magnesium-thorium alloys are considered sealed sources except during repair operations which remove metal.

(4) Radioactive contamination potential. There is no potential while the parts are in service or storage. Contamination results from machining, cutting, drilling, welding, and grinding operations.

(5) Radioactive waste generated. Grindings, filings, grinding oils, and broken parts are disposed of as radioactive waste. During grinding of magnesium-thorium alloys, water is used to prevent fires. This water is collected in the hood sump and the water is filtered prior to release to the environment. Both liquid filters and high-efficiency particulate air filters for the hoods are disposed of as radioactive waste. The waste volume generated is not large enough to require a specific storage facility.

(6) Potentially contaminated area. This is limited to the hoods, exhaust ductwork, and immediate area in which repair operations are conducted.

2-6. Sources and Characteristics of Mixed Waste

a. General.

(1) A mixed waste may be a listed and/or characteristic waste that is mixed with an NRC-regulated radioactive material. The radioactive components of mixed waste regulated by the NRC or the agreement state are source, by-product, or special nuclear material, and the hazardous component of mixed waste is regulated by the

EPA or the RCRA authorized state. A hazardous waste is defined in 40 CFR 261 as a solid waste which exhibits a hazardous characteristic, is "listed" in the regulations, or is a mixture of hazardous and solid wastes.

(2) Radioactive materials that are not source, by-product, or special nuclear materials are not regulated by the NRC, but may be regulated by agreement states, depending on the state laws. Hazardous wastes that are not RCRA listed or characteristic hazardous wastes may be regulated by the state as a hazardous waste under state hazardous waste management laws. The state does not need to be RCRA-authorized to establish this authority. When non-NRC regulated radioactive materials are mixed with RCRA hazardous wastes, or with state-listed hazardous wastes, or when NRC-regulated radioactive materials are mixed with state-listed hazardous wastes, the waste is considered combined waste, which is sometimes called co-mingled waste.

(3) The distinction between mixed and combined or co-mingled waste is important due to disposal options. There are a number of disposal options for combined or co-mingled waste, but only a few options for mixed waste. Several common types of mixed waste are described below. Table 2-2 cross-references types of mixed wastes with sites where each type of mixed waste is commonly found.

b. Organic liquids.

(1) Organic liquids are produced by a large number of LLRW generators, and the particular chemicals which may be components of MW include the full suite of hazardous/toxic chemical industry products. Scintillation fluids, which are used in diagnostic tests and general laboratory counting procedures for environmental and facility monitoring, comprise a large volume of MW. These fluids typically contain toluene and xylene. Note that scintillation 'cocktails' containing tritium and carbon-14 at activities below 0.05 μCi/g, can be disposed of without regard to their radioactivity and so are not considered to be mixed waste. However, these scintillation fluids may still be considered a hazardous waste. Since 1990, a number of manufacturers have marketed nonhazardous liquid scintillation fluids that are biodegradable. These cocktails are not considered mixed wastes, and if the radionuclides are tritium or carbon-14 and are below 0.05 μCi/g, they are not considered radioactive waste and so are landfill disposable.

Table 2-2
Mixed Waste Types and Sources

	Types						
Sources	Scintillation Liquids	Organic Liquids	Heavy Metals	Oils	Metallic Lead	Biological	Other
Mines		x	x		x		
Reactors	x	x	x	x	x		
Fuel Processing Facilities	x	x	x		x		x
Atomic Weapons Mfg.	x	x	x				x
Weapons Maintenance		x	x				x
Uranium/Thorium Mills			x		x		
Labs	x	x	x		x	x	x
Hospitals	x	x			x		x
DoD Maintenance Facilities		x	x	x	x		x
Base Disposal Cells			x		x		
Research Facilities	x	x	x	x	x	x	x
Gas Diffusion Facilities							
DoD Logistics Instruments and Articles Storage Areas			x	x	x		

(2) Organic liquids are also generated by the DOE and commercial industries during the manufacture and maintenance of weapons materials and components, sealed sources, pharmaceuticals, radiopharmaceuticals, and diagnostic tests. DOE, commercial industries, and nuclear power plants use organic chemicals, such as acetone and chlorofluorocarbons for cleaning tools, equipment, and instrumentation. Trash can also be contaminated with organic chemicals. Each MW site must be specifically evaluated as to the nature of potential organic waste components.

c. Metallic lead. Metallic lead may become radioactively contaminated when it is used as a shielded container to store radioactive materials or to shield workers from radiation exposure. This lead may be in the form of foil, sheets, bricks, or containers for storage or shipping. Some states have regulations exempting lead used as shielding from classification as a hazardous waste. In California, for example, lead used as shielding in disposed wastes is considered as a scrap metal. If lead is decontaminated, the cleaning solutions containing dissolved lead and radioactive material may be classified as a mixed, combined, or co-mingled waste. Management of lead as a scrap metal or as a hazardous waste is not covered under this document.

d. Heavy metals. The Army and Air Force use many radionuclides for illumination purposes, and use thorium, which is naturally radioactive, in metallic alloys. Both illuminators and magnesium-thorium (mag-thor) parts often contain heavy metals, that if leachable, constitute mixed, combined or co-mingled waste. Weldingrods containing cadmium, a hazardous heavy metal, are used throughout industry.

e. Oils and lubricants. Waste oils and oily trash, principally from radioactively contaminated machine shops, and when drained from engines that use radioactive wear tracers are considered hazardous under some state regulations. The EPA does not regulate waste oil, in and of itself, as a hazardous waste.

f. Biological materials. Biological materials including carcasses, tissue samples, excreta, and cultures often contain radioactive materials. Though not classified as a hazardous material, there are safety and health considerations, and disposal considerations that must be taken into account for work with radioactive biological materials.

g. Disposal. Several facilities are currently licensed to dispose of MW. Each requires some form of treatment prior to disposal and many are limited to the types of hazardous wastes and radionuclides they can accept. These disposal facilities use shallow land burial, deep well injection, incineration, air effluent release, and recycling to dispose of wastes. The HTRW CX maintains information on available disposal methods. Mixed, combined, or co-mingled waste that cannot be treated and disposed of as ordinary trash, LLRW, or hazardous waste will have to remain in storage until disposal facilities are available to accept it.